

# SYNTHESIS OF A COUNTRY-WIDE CAPACITY OPERATIONAL SNAPSHOT

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## ABSTRACT

The development a comprehensive analysis of the operational status on all of South Africa's higher order roads presented a significant analytical challenge. The National Department of Transport National Transport Masterplan 2050, required that a determination of road infrastructure service capacity and bottlenecks be made on a provincial and national level.

The operational analysis entailed the development of a comprehensive transportation model. This transport model takes into account the numerous variables that impact on future transportation behaviour on the county's major transport ways and will make strategic estimates on the demand for travel and transportation across a number of modalities. Socio-economic projections, future infrastructure plans and existing demand estimates are incorporated to estimate future demand.

The development of this model is however a very time-consuming and data hungry process. A means was sought to establish an operational snapshot on higher order roads, using the known characteristics of existing road infrastructure supported by available traffic volumes as base. This data was also applied to determine estimated time-frames on when infrastructure upgrades would be required to cope with demand on a country-wide basis, assuming that no meaningful alternatives are put in place such as rail, etc.

The required operational snap shot presented significant challenges in terms of data requirements. A feasible methodology had to be selected to perform such analysis recognising the availability of existing data and the ultimate credibility of the findings. The methodology contained in the Highway Capacity Manual (HCM, 2000) presented the best recourse in the lights of the objectives that were set for this process, in particular the specific methodologies prescribed for the analysis two-lane and multi-lane freeways (Chapter 20 and 21).

Another alternative that was considered was to use the Highway Traffic Model (HTM). The HTM model was recently developed by the South African National Roads Agency Limited. Based on an appraisal of the data requirements of these two alternatives, it was decided to select the HCM method as the data synthesis process required to do analysis using this method, on this scale, presented the most feasible option. The scale of analysis undertaken, involved the analysis of 54,972km of provincial and national roadways.

This paper serves to provide a synopsis of the analysis procedures undertaken, basic findings of the analysis, basic findings on the methodology used as well as lessons learnt from a national/provincial road infrastructure operational performance sketch planning approach for the National Transport Masterplan 2050.

# 1. INTRODUCTION

A strategic deliverable for the National Transport Masterplan 2050 was the preparation of a demand model in order to make strategic estimates on the demand for travel and transportation across a number of modalities within the South African Transport Environment. This model had to take into account the numerous variables that impacts on future transportation behaviour on the country's major transport ways such as socio-economic projections, future infrastructure plans as well as existing demand estimates.

The development of such a model is a costly and time consuming task which occupied much of the overall project timeframe. During the course of the project execution a need was identified to determine the overall status of road-based transportation on the country's roads based on existing traffic demand and existing infrastructure to accommodate this demand. Information to develop a "snapshot" of the existing operating conditions on all of the country's major roadways was collated and formed the foundation of the development of a strategy to analyse and represent key performance indicators on the operational characteristics of the country's high order roads.

The aim of this paper is to provide a synopsis of the HCM analysis procedures undertaken, basic findings of the analysis, basic findings on the methodology used as well as lessons learnt from a national/provincial road infrastructure operational performance sketch planning approach for the National Transport Masterplan 2050.

The challenge that had to be overcome, was to find methodologies to address data requirements in a way that would produce meaningful results, on such a large scale and that would allow for further refinement and tweaking on certain sections, should this be required.

The determination of service capacity and bottlenecks on a provincial and national level presented significant challenges in terms of:

- Data input requirements and
- Selection of a suitable methodology to process and model the data to produce capacity and level of service results.

The strategic nature of the analysis had to be taken into account as well as realistic time-frames in which meaningful results could be produced. The methodology contained in the Highway Capacity Manual (TRB, 2000) was selected as the most appropriate methodology to adopt for this purpose. The specific methodologies prescribed for the analysis two-lane and multi-lane freeways are of relevance (Chapters 20 and 21).

## 2. DEFINING CONCEPTS USED IN THE ANALYSIS

### 2.1 TWO-LANE AND MULTI-LANE FREEWAY SECTION DEFINITIONS

The definition of a two-lane freeway is a single-roadway providing for two-way traffic. Traffic travelling in a particular direction, wishing to overtake slower moving vehicles, therefore has to make use of overtaking opportunities allowed by the absence of barrier (no-overtaking) lines (informed by the road's horizontal and vertical alignment) and gaps in the stream of oncoming (opposing) traffic. Generally in the South African roads environment, rural roads tend to fall under this description.

Multi-lane freeways, on the other hand, generally tend to occur in the proximity of urban / metropolitan areas. A multi-lane freeway provides for multiple lanes of travel per direction. This type of roadways generally is divided by a median barrier in the middle of the road although this is not a requirement for this particular classification. The major difference

however lies in the traffic's ability to overtake slower moving vehicles without having to contend with oncoming traffic flowing in the opposing direction.

## 2.2 MEASURES OF EFFECTIVENESS

The key performance indicator that is used to evaluate the status of vehicular operations on a roadway is expressed in terms of Level of Service (LOS). LOS is indicated by using the letters of the alphabet ("A" through to "F"), "A" representing the best operating conditions and "F" the worst. When new road infrastructure is designed, most public sector entities tend to require a design LOS of at least "C" in the design year (for the 30<sup>th</sup> highest hour or peak hour) – in other words, if a facility is designed to last for a period of seven years, in year seven the facility should preferably still operate at a LOS of "C". The reality within most countries, however, is at a level that is usually exceedingly lower than this ideal situation, especially in and around urban environments.

The LOS for different kinds of analysis is determined using different approaches as recommend by the HCM. For two-lane and multi-lane freeways the approaches to measure LOS also differs but provides the practitioner with results that are comparable from one type of facility to the next.

- Two-lane facilities

LOS is determined in terms of both *percent time-spent-following* and *average travel speed*. These two factors provide a representative measure of the efficiency of mobility. The worst of the two measures is taken as representative of the facility.

- Multi-lane facilities

LOS is determined as a relationship between the *average passenger-car speed* and the *traffic density*. It provides an indication of the freedom of a vehicle to manoeuvre within the traffic stream as well as the vehicle's proximity to other vehicles.

## 3. SUMMARY OF HCM CALCULATION METHODOLOGY

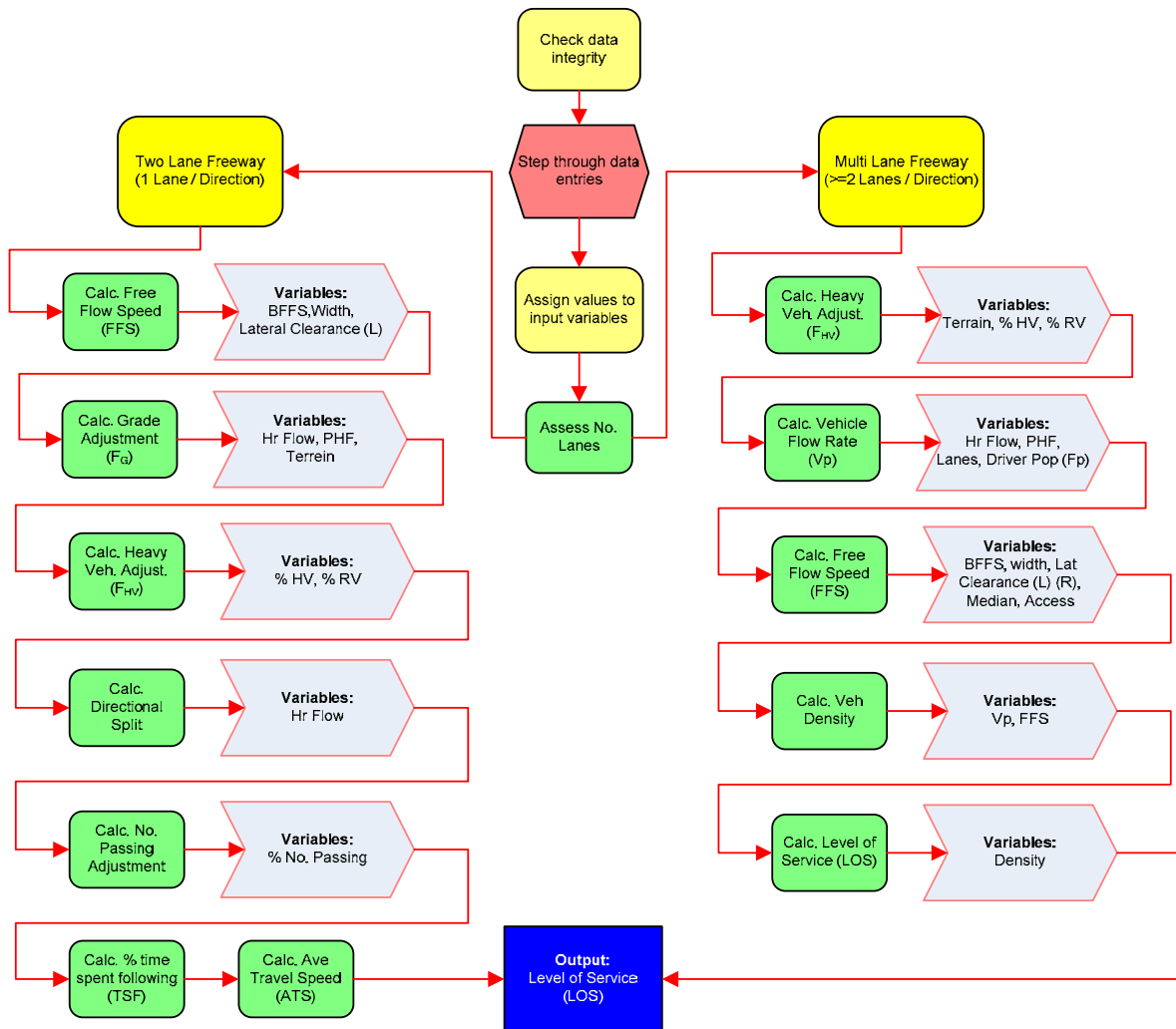
### 3.1 BASIC CONCEPTS OF THE METHODOLOGY

A computer model that was developed, by Aurecon based on the HCM methodology, was used. The process flow of the model is shown in [Figure 1](#). The data was prepared for processing making use of various electronic databases and a GIS system. Approximately 12,800 individual, homogenous, directional links ( $\pm 54,000\text{km}$ ) were identified for the process of analysis. For each homogenous section of road, the following information was calculated:

- The LOS in the base year (selected base year was 2005);
- The LOS in the target year (selected target year was 2025);
- The estimated vehicular flow in the target year at an assumed traffic growth rate;
- The estimated vehicular flow at which a threshold/target LOS of "D" will be reached for each roadway segment analysed;
- The year during which the threshold/target LOS will be reached assuming no upgrades and an assumed traffic growth rate;
- The number of additional lanes required per direction in order to achieve/maintain the threshold/target LOS for each road segment analysed;
- The LOS that will be achieved within the target year assuming that the additional required lanes are provided.

The benefit of following this methodology is that it aligns with international best-practice. Furthermore, it is possibly the first time that an analysis of this nature is undertaken on this magnitude. The methodology allows for refinement of results on selected roadways by refining the accuracy of input data in order to achieve this. It further provides a first-order estimate of the actual operating conditions on all of South Africa's major roadways thereby allowing quick insight into the scale of upgrading that would be required to maintain a nominal economic growth rate over time. This is based on the assumption that for at least the next 20 years, South Africa will remain dependant on road-based transportation as a fundamental part of commuter, recreational and freight transportation.

**Figure 1: HCM Two-Lane and Multi-lane Freeway Analysis Process Flow**



## 4. DATA REQUIREMENTS AND ASSUMPTIONS

### 4.1 AVAILABLE DATA

The data input requirements for the modelling process was obtained from existing databases and GIS systems that were made available by the South African National Roads Agency and the respective provinces and metros. The data included:

- Traffic Counts

A range of traffic counts that were collated over time by means of electronic counting stations was used (some permanent and some temporary) – this assisted in the determination of LOS for each road and providing the percentage heavy vehicles as well as the directional split.

Typical methods of representing traffic flow data include the Average Daily Traffic (ADT), "hourly observed traffic volume" or the "30th (thirtieth) highest hour" or "100th (hundredth) hour".

Typically road usage is measured by Average Daily Traffic in both the national and provincial traffic counting programs. This measure is however not detailed enough to accurately measure road capacity and constraints. A more appropriate measure for determining capacity constraints would be Volume-Capacity (V/C) ratios and Level-of-Service (LOS). V/C ratios and LOS cannot be calculated directly from ADT. ADT must be converted to the 30th Highest Hour of vehicle volumes, which is generally accepted as being representative of peak period conditions.

To predict hourly flows, it is necessary to know the ADT and the peaking factor,  $\beta$ . The peaking factor ( $\beta$ ) is a descriptor of the traffic flow on a given road and depends on factors such as the percentage and incidence of holiday traffic, the relative sizes of the daily peaks, etc.

The peaking factor can fluctuate between -0,1 and -0,4. A value of -0,1 indicates minimal seasonal peaking. This value of  $\beta$  should be used in urban designs. A value of -0,4 suggests very high seasonal peaks and would normally be applied to National roads. As a general rule, a value of -0,25 could be used as being a typical value, although refinements were made to these values by various entities that were responsible for the analysis of each province.

The following equation should be used to convert ADT to the 30th Highest Hour:

$$QN = 0.072 \times ADT \left( \frac{N}{1030} \right)^\beta$$

Where:

QN = Two-directional flow in Nth hour of year (veh/h)

ADT = Average daily traffic (veh/day)

N = Hour of year

$\beta$  = Peaking factor

Applying a value of -0,25 to  $\beta$ , and assuming N to be 30, QN according to the above equation is 0,146 x ADT for 30th highest hourly flow.

- Road Cross Section

Road cross section data was collected from GIS datasets for each homogenous road analysis section including number of lanes, width of lanes, width of road shoulders and the presence of a median.

- Geographical Location

The geographical location of each homogenous road analysis section was determined from a GIS which assisted with the stratification of results per province. This information also assisted in making informed assumptions about the traffic composition such as the number of recreational vehicles and daily commuters within the respective traffic streams.

- Topography

The topography traversed by the road (rolling, flat or mountainous) was derived from the GIS contour map. This assisted in estimating the effects on flow and capacity caused by heavy vehicles and recreational vehicles and provided input into the estimation of percentage no-passing zones per roadway.

## 4.2 TRAFFIC GROWTH ASSUMPTIONS

Given that traffic growth as a critical factor in the sustained operational performance of a road, a suitable growth rate had to be determined for the analysis period. Given that the NATMAP Transport Demand Model determines future traffic growth based on socio-economic scenario planning, the project team concluded that a Demand Model linked traffic growth would be more realistic than a single digit assumed growth rate for the analysis.

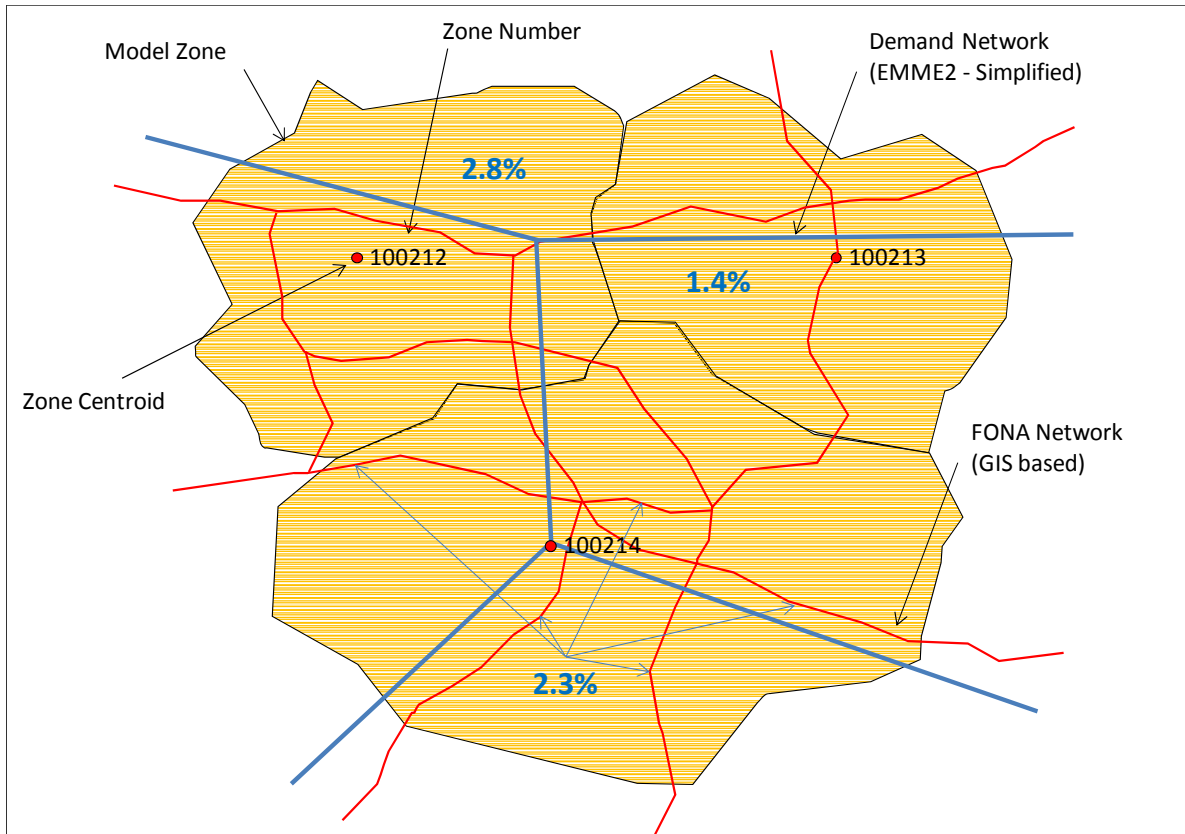
This decision posed a problem in that the NATMAP Transport Demand Model (EMME2) and HCM model had two distinct road networks. The Transport Demand Model used a more simplified model network focusing on roads of national importance (typically National Roads and Provincial Roads of strategic importance) linking land-uses of strategic significance of the country. The EMME2 network is also more simplistic and simplifies road geometries into straight lines.

The HCM Model road network, on the other hand, was more complex including many more provincial roads than the EMME2 Transport Demand Model, and furthermore followed the actual GIS road alignment as opposed to a simplified geometry.

Given the network disparities between the two models, the link between the Transport Demand Model and HCM Model was established at a Transport Demand Model Zone level as shown in [Figure 2](#). Each Zone in the Transport Demand Model has a specific growth rate for trip generation purposes which is based on socio-economic and demographic projections. These growth rates were assigned on a link-by-link basis from the EMME2 Transport Demand Model Zone to the associated HCM model links contained within each specific zone.

This link enabled the HCM model to project current base year traffic volumes (2005) into the future for various horizon years (i.e. 2030 and 2050) and for various modelled scenarios (i.e. NATMAP 2050 high, medium and low growth scenarios).

**Figure 2: Link between Transport Demand Model (EMME2) and HCM Model**



## 5. MODEL APPLICATIONS AND RESULTS

The HCM model was used to determine the following:

- Network LOS for 2005 (base year), 2030 and 2050 horizon years (with no future upgrades)
- Future network upgrade requirements in order to attain or maintain a minimum LOS D level of operations

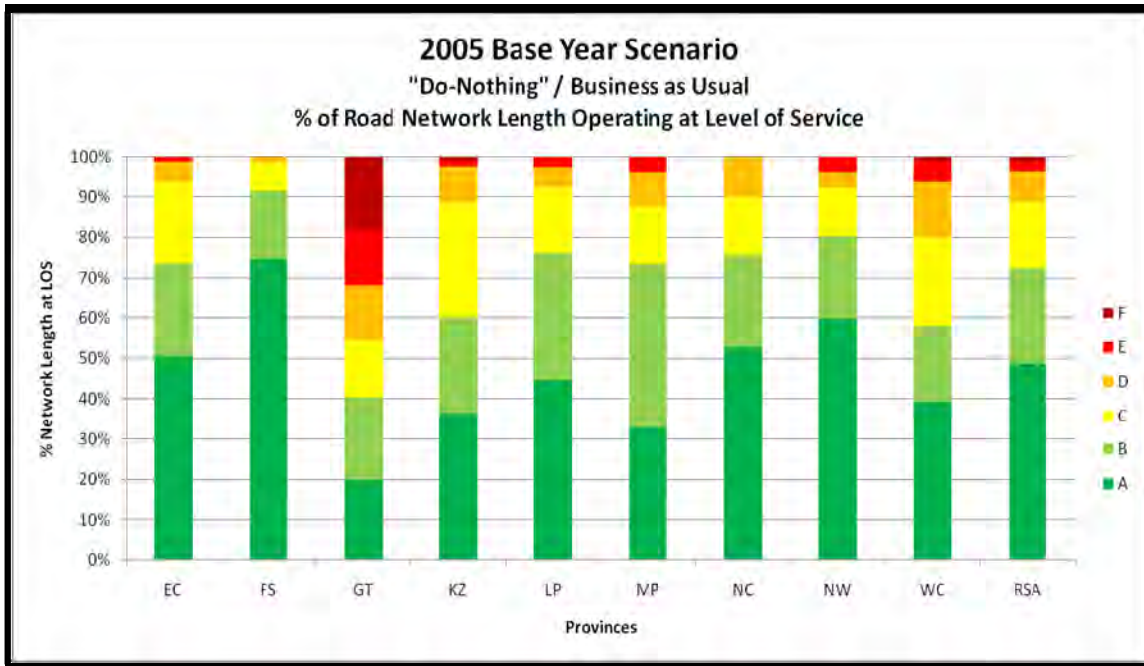
### 5.1 DO NOTHING SCENARIO” – FUTURE CAPACITY CONSTRAINTS

A Level of Service calculation was undertaken for all links of the FONA road network for the following scenarios:

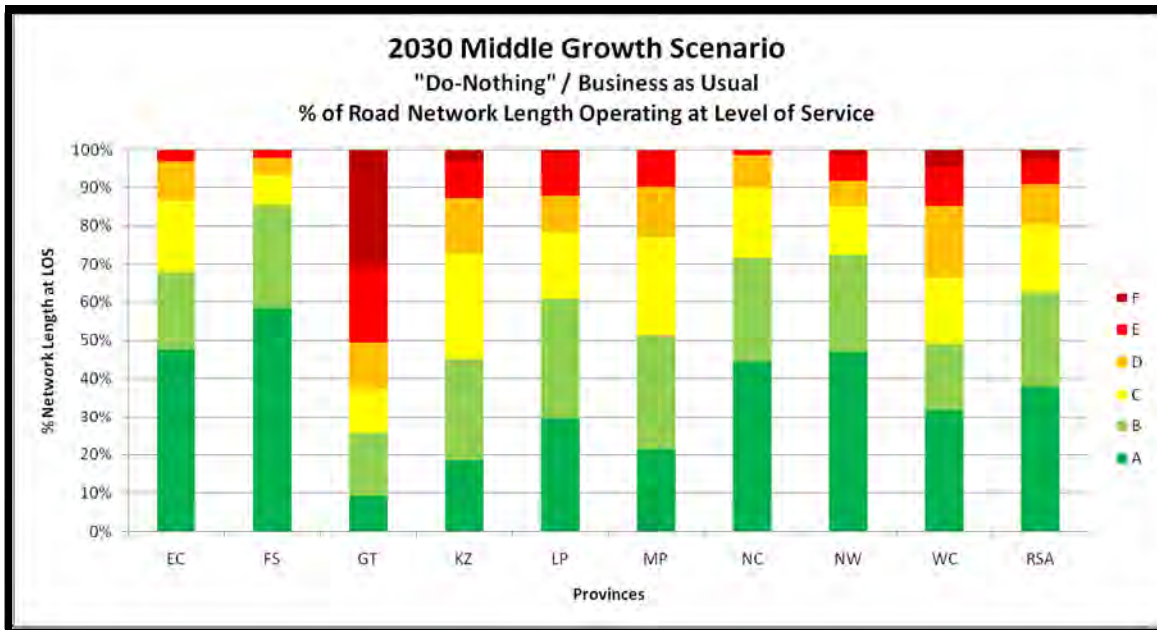
- 2005 Base Year (Refer to [Figure 3](#))
- 2030 Middle Growth Scenario (Refer to [Figure 4](#))
- 2050 Middle Growth Scenario (Refer to [Figure 5](#))

The results from the analyses are shown in the subsequent tables.

**Figure 3: 2005 Base Year - % of Road Network Operating at LOS**

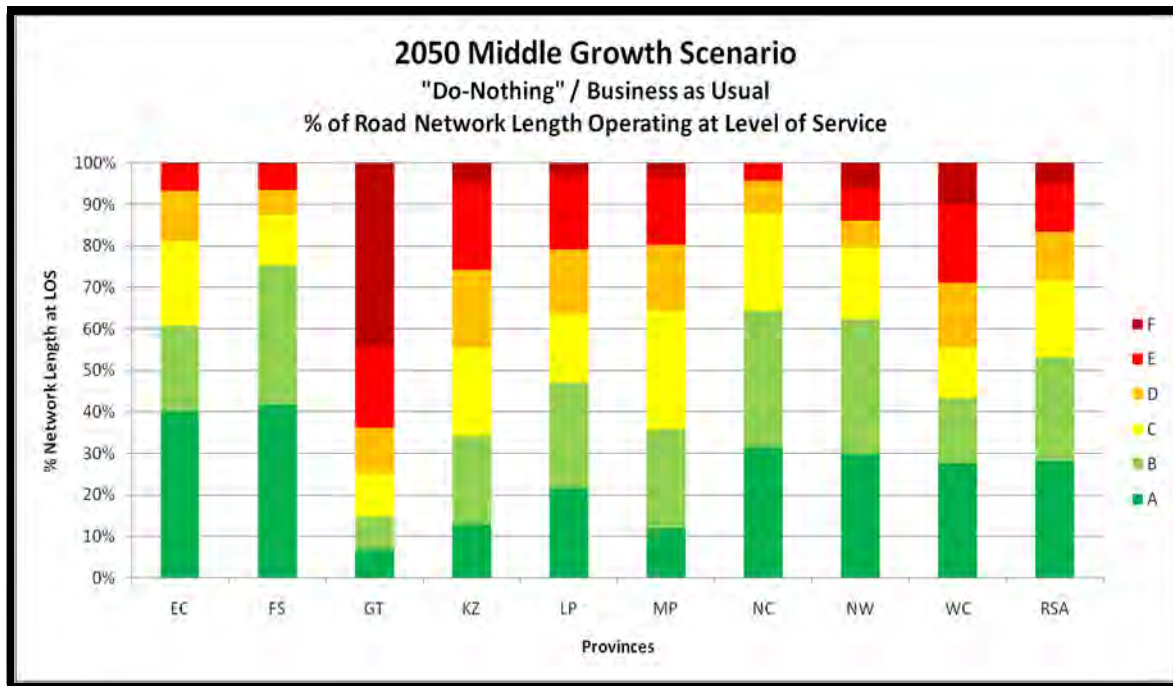


**Figure 4: 2030 Middle Growth Scenario - % of Road Network Operating at LOS**





**Figure 5: 2050 Middle Growth Scenario - % of Road Network Operating at LOS**



The results from the Capacity Analyses are shown in [Table 1](#) below.

**Table 1: % Road Network per LOS Class per Year (Middle Scenario)**

Scenarios	A	B	C	D	E	F	Total
RSA 2005	48.6%	23.7%	16.3%	7.5%	2.7%	1.1%	100.0%
RSA 2030	38.0%	24.8%	17.4%	10.5%	6.8%	2.5%	100.0%
RSA 2050	28.1%	25.1%	18.6%	11.6%	11.4%	5.2%	100.0%

Maps showing the LOS analysis results for the base year (2005) and the design years (2030 and 2050) are shown in [Appendix A](#), [Appendix B](#) and [Appendix C](#) respectively.

## 5.2 UPGRADING REQUIRED FOR FUTURE YEARS

In order to determine the upgrade requirements for future years, a HCM calculation was undertaken to determine the following:

- The LOS in the selected target year
- The estimated vehicular flow at which a threshold/target LOS of “D” will be reached for each roadway segment analysed;
- The year during which the threshold/target LOS D will be reached assuming no upgrades will take place;
- The number of additional lanes required per analysis direction in order to achieve/maintain the threshold/target LOS D;
- The LOS that will be achieved within the target year assuming that the additional required lanes are provided.

Based on the Target LOS analysis and the additional lane requirement calculations the following observations can be made:

- According to the methodology applied, lane additions are warranted once LOS “D” is exceeded.
- The HCM methodology continually adds lanes to network links until the LOS is improved beyond the LOS D level. Although it is not always realistic to continually add lanes to address capacity constraints – this process is useful to identify areas on a vast road network where more detail investigation is required.

Maps showing the Additional Lane analysis results for the base year (2005) and the design years (2030 and 2050) are shown in [Appendix D](#), [Appendix E](#) and [Appendix F](#) respectively.

## 6. PARAMETER SENSITIVITY ANALYSIS

In order to fully understand the complexities of the HCM two-lane and multi-lane calculation methodologies for validation and calibration purposes a rigorous parameter sensitivity analysis was undertaken. Each of the model parameters was tested against a control data set by calculating results (i.e. LOS trigger volumes) for each of the parameter input values through their range of possible inputs. [Table 2](#) shows the input parameters that were subjected to sensitivity analysis.

Each of the input parameters was tested, across their range of variability, against a network set at optimal performance parameters. The optimal network performance parameters are defined as follows:

- Lane width = 3.7m
- Lateral Clearance > 1.8m
- Traffic Flow (Analysis direction) = Linear increasing in 5 vehicle intervals
- Opposing flow = Linear increasing in 5 vehicle intervals
- Percentage heavy vehicles = 0%
- Percentage Recreational vehicles = 0%
- Peak Hour Factor (PHF) = 0.95
- Terrain type = Level terrain
- Driver population (fp) = 1 (Commuter / weekday traffic / familiar drivers)
- Level of access per kilometre (LOA/km) = 0 accesses per kilometre
- Base free-flow speed (BFFS) = 100km/h
- Percentage no-passing on link = 0% no passing

The results from the sensitivity analyses will be discussed in the subsequent sections of the paper.

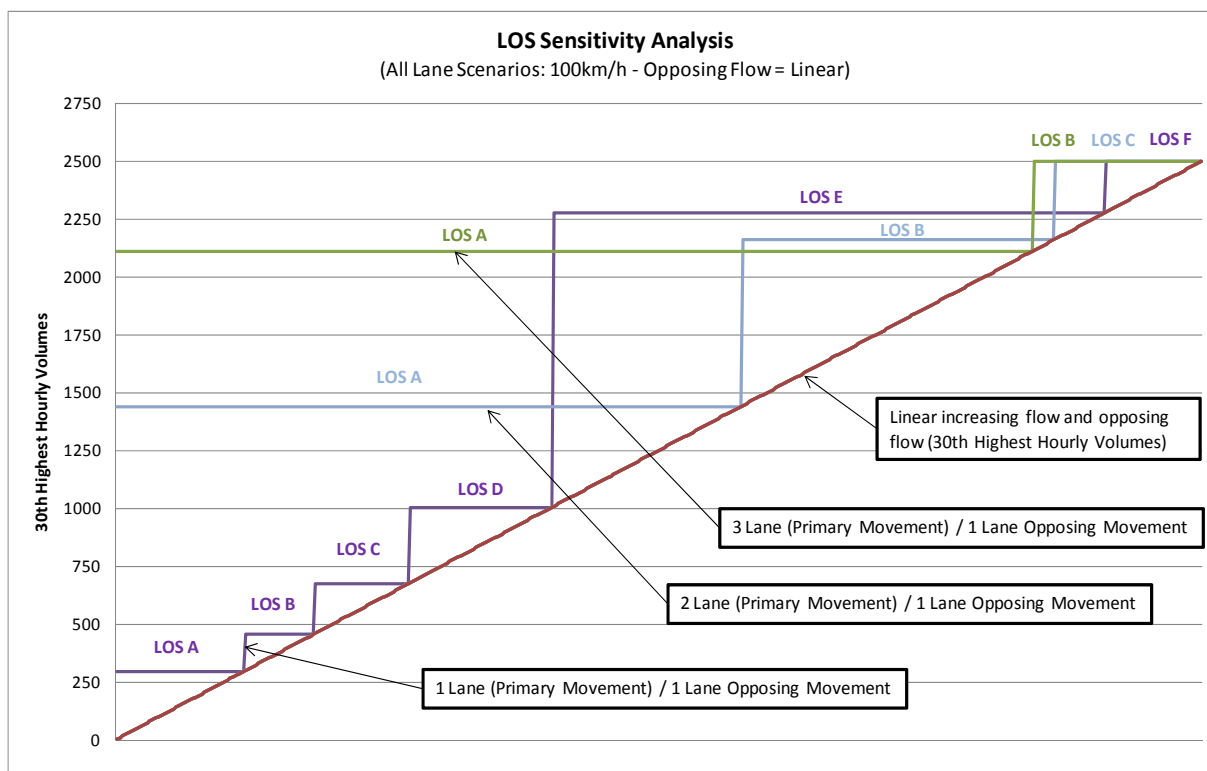
**Table 2: HCM Two-lane and Multi-lane Parameters subjected to Sensitivity Analysis**

No.	Data Field	Description	Scenario Description	Range	Optimum
1	Lanes	Number of lanes (Base year scenario)	Scenarios ranging from 1 to 4 lanes (Interval = 1 lane).	1 to 4 lanes	3
2	Lane_width	Lane width (m)	Scenarios ranging from 3.0m to 3.9m lane widths (Interval: 0.1m).	3.0m to 3.9m	3.7m
3	Verge_width_L	Lateral clearance distance to obstacle next to road	Scenarios ranging from 0m to 1.8m both sides (Interval: 0.2m)	0m to 1.8m	>1.8m
4	Verge_width_R				
5	Opp Flow	Opposing Flow (Same hour as 30th Highest Hourly Volume)	Scenarios ranging from 100 to 1000 opposing flow (Interval: 100 vehicles).	0 to 1000	0
6	%HV	% Heavy vehicles in traffic stream (Base year scenario)	Scenarios ranging from 0% HV to 60% HV (Interval: 5% HV).	0% to 100%	0%
7	%RV	% Recreational vehicles in traffic stream	Scenarios ranging from 0.5% (Urban) to 5% (Rural) (Interval = 0.5%)	0% to 50%	0%
8	PHF	Peak Hour Factor	Scenarios ranging from 0.80 to 0.98 PHF (Interval = 0.02) (Categorization: Urban = 0.92 / Rural = 0.88)	0 to 1.0	1
9	Terrain	Terrain type (proxy for link gradient)	Scenarios ranging from "Mountainous", "Rolling" and "Level".	Level to Mountainous	Level
10	Driver_Pop (fp)	Driver Population Indicator	Scenarios ranging from 0.80 to 0.90 (Interval = 0.05) (Categorization: Commuter Traffic (Urban - Weekday) = 1.0 / Rural Traffic = 0.85)	0.85 to 1.0	1
11	LOA/km	Number of accesses per kilometre of link	Scenarios ranging from 0 to 24 accesses per kilometre. (Interval = 2 accesses per kilometre)	0 to 24 Accesses	0
12	BFFS	Base Free Flow Speed	Scenarios ranging from 70km/h to 100 km/h (Interval = 5km/h).	>70km/h <100km/h	100km/h
13	%No_Pass	% of link with no passing opportunities	Scenarios ranging from 0% to 90% no passing opportunity along each link (Interval = 10%).	0% to 90%	0%

## 6.1 NUMBER OF LANES

The HCM methodology shows that LOS trigger volumes are *highly elastic (highly sensitive)* in response to lane additions on the network. Although it was anticipated that LOS is highly responsive to lane additions, the degree of responsiveness was underestimated. Changing the analysis road network from 1 lane to 2 lanes in the primary direction of travel results in a significant network LOS improvement whereby all links fall within the LOS A, B and C categories. LOS D, E and F were completely removed by adding an additional lane. Adding a subsequent third lane to the analysis network results in all links either operating and LOS A or B (Refer to [Figure 6](#)).

**Figure 6: Number of Lanes – LOS Sensitivity Analysis Results**



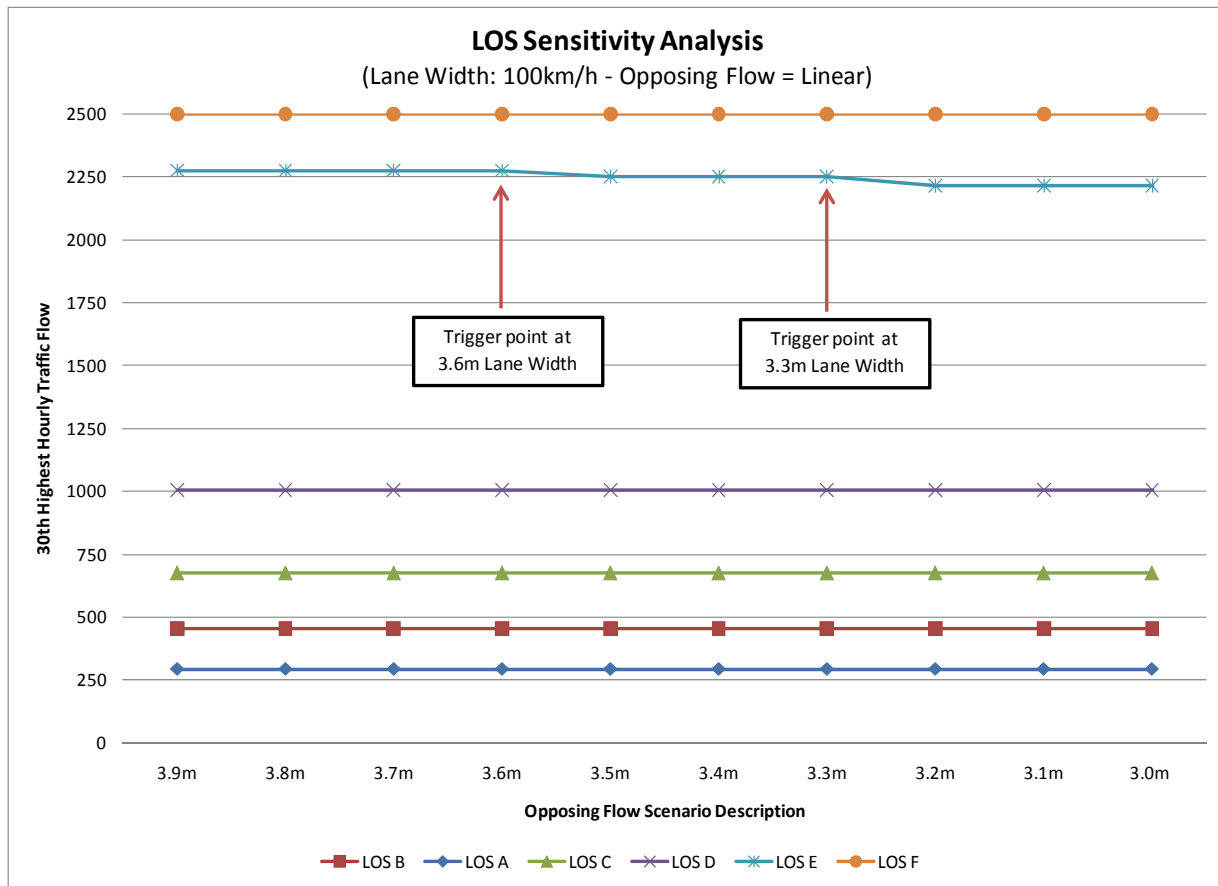
Scenario Statistics: 3 scenarios, 1500 links, Linear increasing traffic volumes, Interval: 1 lane added per scenario.

## 6.2 LANE WIDTH

The HCM methodology shows that LOS trigger volumes are *relatively inelastic (insensitive)* in response to lane width changes on the network (Refer to [Figure 7](#)). The sensitivity analysis shows, LOS trigger volumes only respond to lane width changes at 3.3m and 3.6m lane widths.

Therefore, only three levels of lane width options need to be accommodated in the HCM analysis methodology, namely <3.3m lanes, >=3.3m and <3.6m lanes and >=3.6 m lanes. More research is however recommended on this topic to test sensitivity over a larger range of other parameters in order to quantify the combined effect of parameters.

**Figure 7: Lane Width – LOS Sensitivity Analysis Results**



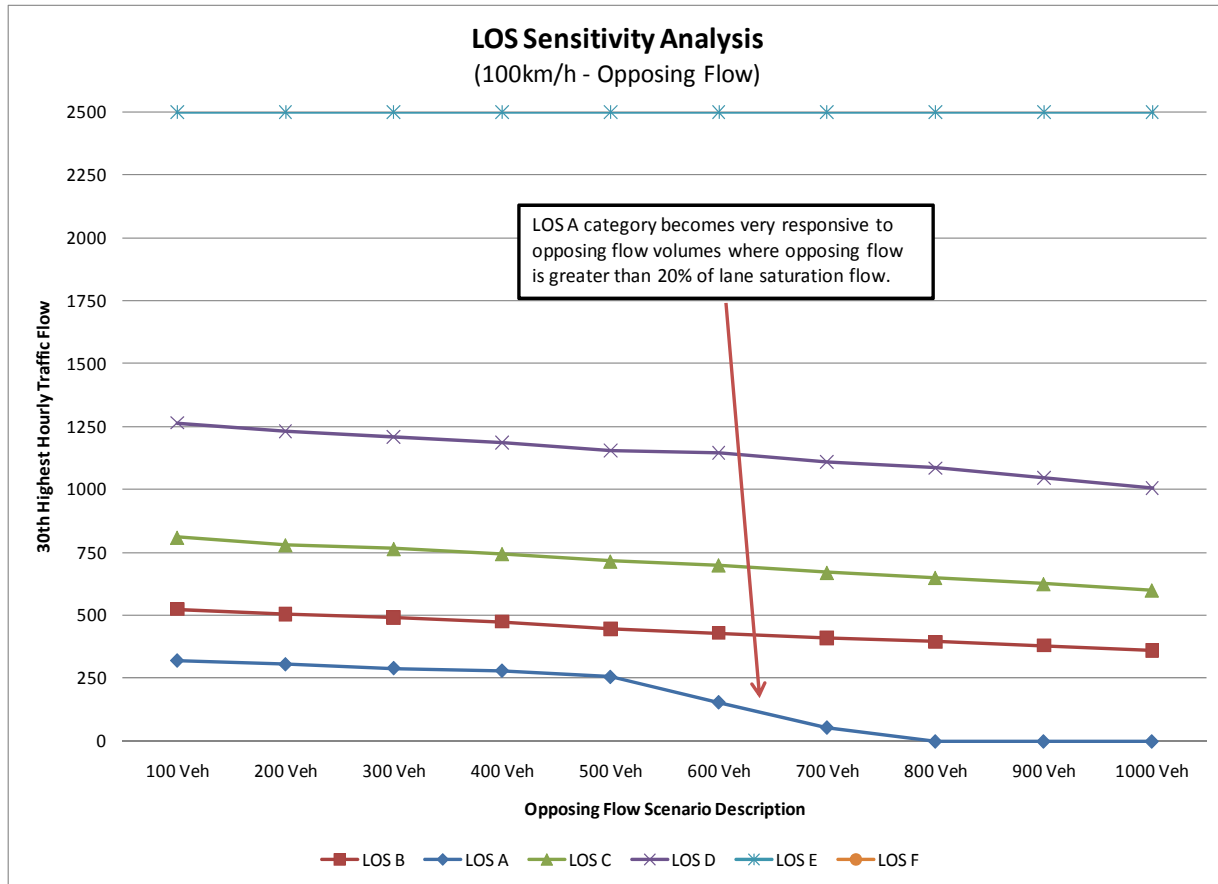
Scenario Statistics: 10 scenarios, 5000 links, Linear increasing traffic volumes, Interval: 0.1m lane width added per scenario.

### 6.3 OPPOSING TRAFFIC FLOW (DIRECTIONAL SPLIT)

The HCM methodology shows that LOS trigger volumes are *relatively elastic (moderate sensitivity)* in response to opposing flow (directional split) changes on the network (Refer to [Figure 8](#)). LOS B, C, D and E categories show linear decreasing trend in response to increases in opposing flow increases. For these categories, for every additional 100 vehicles opposing flow the LOS trigger volume reduces by approximately 3% on average. LOS A also exhibits a linear decreasing trend until the opposing flow equals approximately 500 vehicles. At this point the LOS trigger volumes reduce dramatically at an average rate of 50%. At opposing flow volume of 800 vehicles LOS A category is eliminated from the operational conditions, irrespective of the primary analysis direction traffic volume.

The linear decreasing trend of the LOS category trigger volumes was an unexpected result from the sensitivity analysis. The expectation of the authors was that the LOS category trigger volumes would represent a characteristically negative exponential curve in response to increasing opposing flow volumes.

**Figure 8: Opposing Flow (Directional Split) – LOS Sensitivity Analysis Results**



Scenario Statistics: 10 scenarios, 5000 links, Linear increasing traffic volumes, Interval: 100 opposing flow vehicles added per scenario.

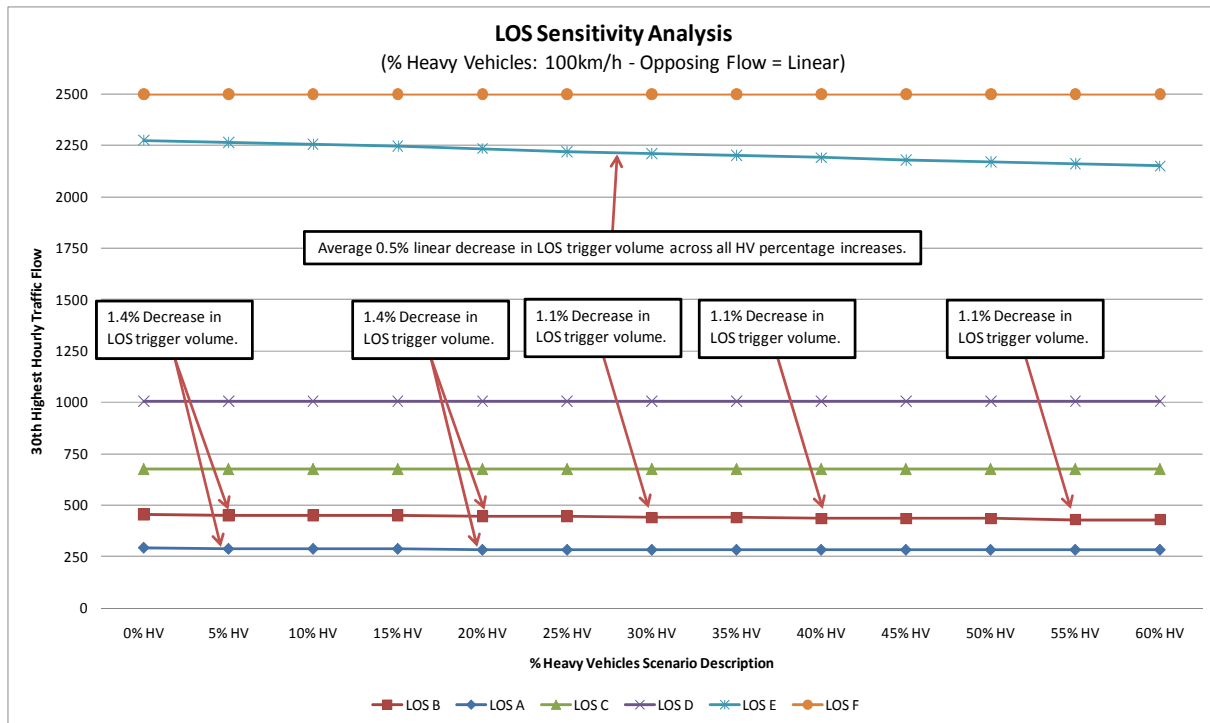
## 6.4 PERCENTAGE HEAVY VEHICLES

The HCM methodology shows that LOS trigger volumes are relatively inelastic (insensitive) in response to percentage heavy vehicles in the traffic stream on the network (Refer to [Figure 9](#)). According to the sensitivity analysis LOS E trigger volumes shows consistent linear sensitivity towards increases in percentage heavy vehicles in the traffic stream. On average, a 5% increase in heavy vehicle volumes results in a 0.5% reduction in trigger volume value for the LOS E category.

LOS A and B categories show sporadic elasticity to increases in percentage heavy vehicles in the traffic stream. On average, a 10% to 15% increase in percentage heavy vehicle volumes in the traffic stream results in an average 1.1% to 1.4% reduction in LOS A and LOS B trigger volume values.

It is expected that the LOS category trigger volumes would represent a characteristically negative exponential curve in response to increasing heavy vehicle percentages in the traffic stream, especially on short sections and on sections characterised by rolling or mountainous topography. Once more it is recommended that more research be undertaken on this matter.

**Figure 9: Percentage Heavy Vehicles – LOS Sensitivity Analysis Results**



Scenario Statistics: 13 scenarios, 6500 links, Linear increasing traffic volumes, Interval: 5% Heavy vehicles added per scenario.

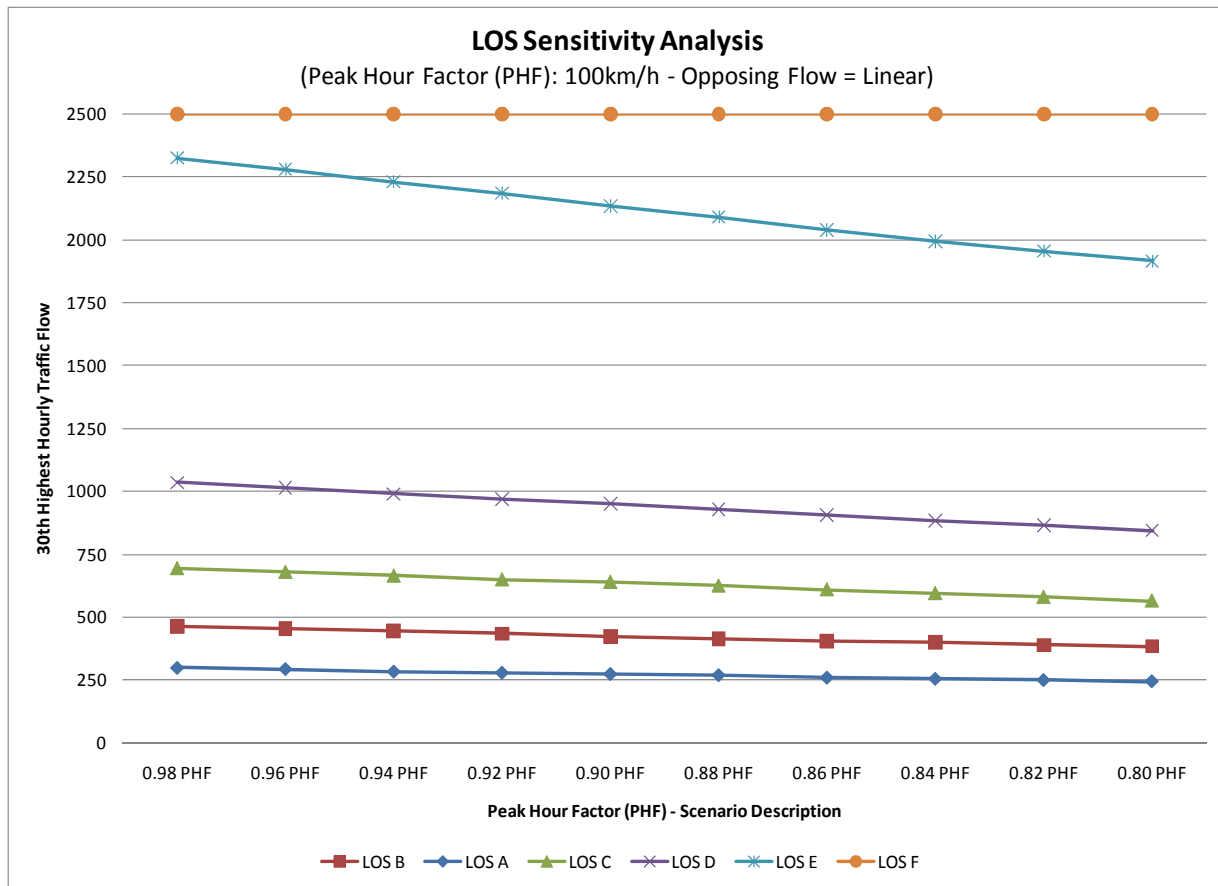
## 6.5 PEAK HOUR FACTOR (PHF)

PHF is defined as the relationship between the peak 15-minute flow rate and the full hourly volume. Peak-hour factors for freeways typically range between 0.80 and 0.95. Lower PHF values are more typical for rural freeways or off-peak conditions – indicative of a high volume of vehicles to be accommodated in one or two specific 15-minute periods within the peak hour. Higher PHF values are typical of urban and suburban peak-hour conditions – indicative of traffic volumes spread more evenly across all 15-minute periods within the peak hour.

The HCM methodology shows that LOS trigger volumes are *relatively elastic (moderate sensitivity)* in response to adjustments to the PHF of the traffic stream on the network (Refer to [Figure 10](#)). On average all LOS category trigger volumes reduce by approximately 2.2% for every PHF change of 0,02. This is surprisingly sensitive for a parameter ordinarily assumed without much consideration by many practitioners.

Higher PHF values (0.98) representing urban scenarios with more evenly spread volumes over the peak hour present higher tolerances across the LOS categories. Lower PHF values (0.80) representing rural scenarios with typically all hourly traffic volumes contained in one or two 15-minute periods within the peak hour have significantly lower LOS category trigger volume tolerances for LOS D and E.

**Figure 10: Peak Hour Factor – LOS Sensitivity Analysis Results**



Scenario Statistics: 10 scenarios, 5000 links, Linear increasing traffic volumes, Interval: 0.02 increase in PHF parameter per scenario.

## 6.6 TERRAIN TYPE

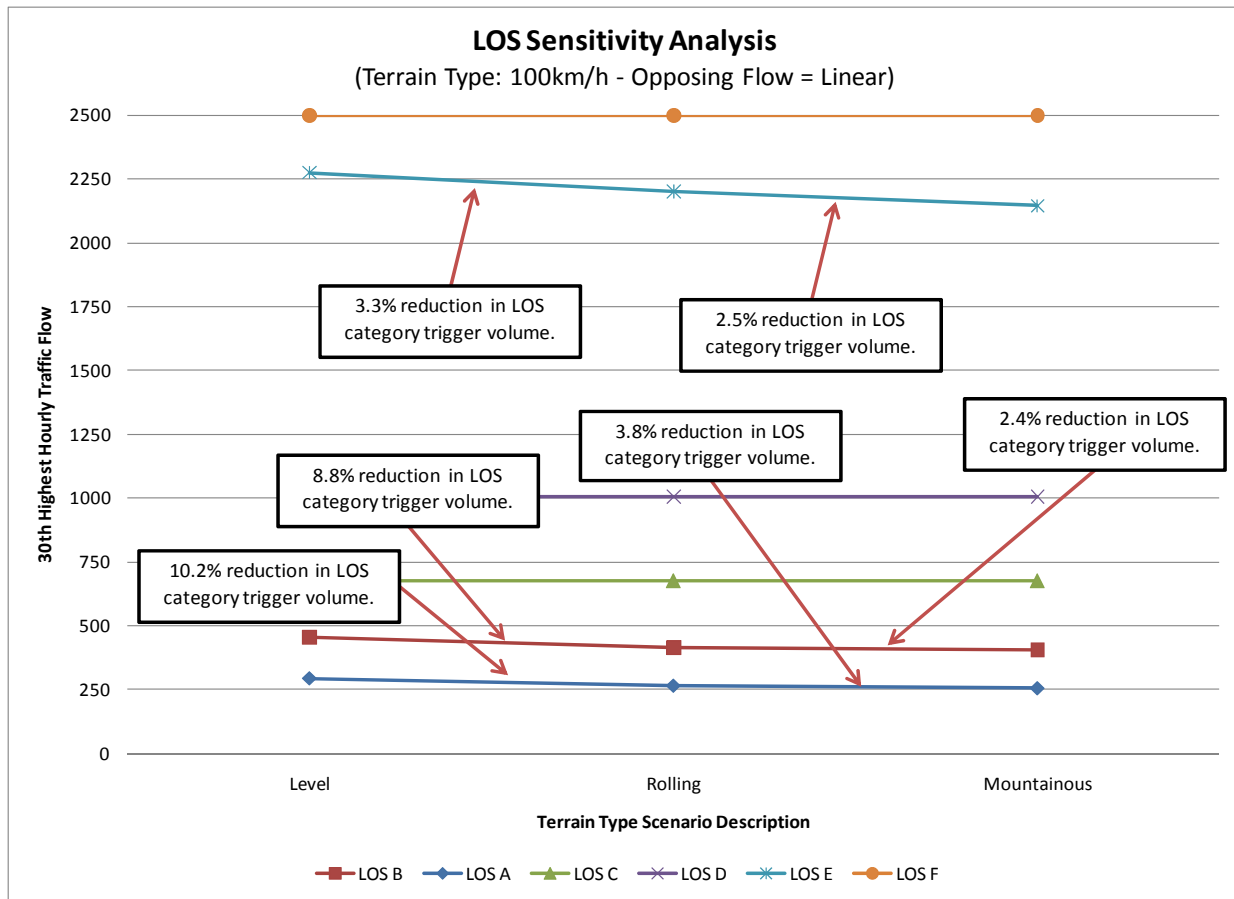
The HCM methodology shows that LOS trigger volumes are *relatively elastic (moderate sensitivity)* in response to adjustments to terrain type associated with each network link (Refer to [Figure 11](#)). According to the sensitivity analysis, LOS category trigger volume values are more responsive to a terrain type change from category “Level” to “Rolling” than from category “Rolling” to “Mountainous”. In addition to this, only LOS categories A, B and E significantly respond to changes in terrain type.

On average, terrain type change from category “Level” to “Rolling” results in a 10.2% reduction in LOS A category trigger volume value and only a 3.8% reduction in trigger volume value for a terrain type change from “Rolling” to “Mountainous”. LOS B category is less responsive than LOS A reflecting a 8.8% reduction in trigger volume value for a terrain type change from category “Level” to “Rolling” but only a 2.4% reduction in trigger volume value for a terrain type change from “Rolling” to “Mountainous”.

LOS E shows almost linear responsiveness to changes in terrain type with a 3.3% reduction in trigger volume value for terrain type change from category “Level” to “Rolling” and a 2.5% reduction in trigger volume value for a terrain type change from “Rolling” to “Mountainous”.



**Figure 11: Terrain Type – LOS Sensitivity Analysis Results**



Scenario Statistics: 3 scenarios, 1500 links, Linear increasing traffic volumes, Interval: Different terrain type per scenario.

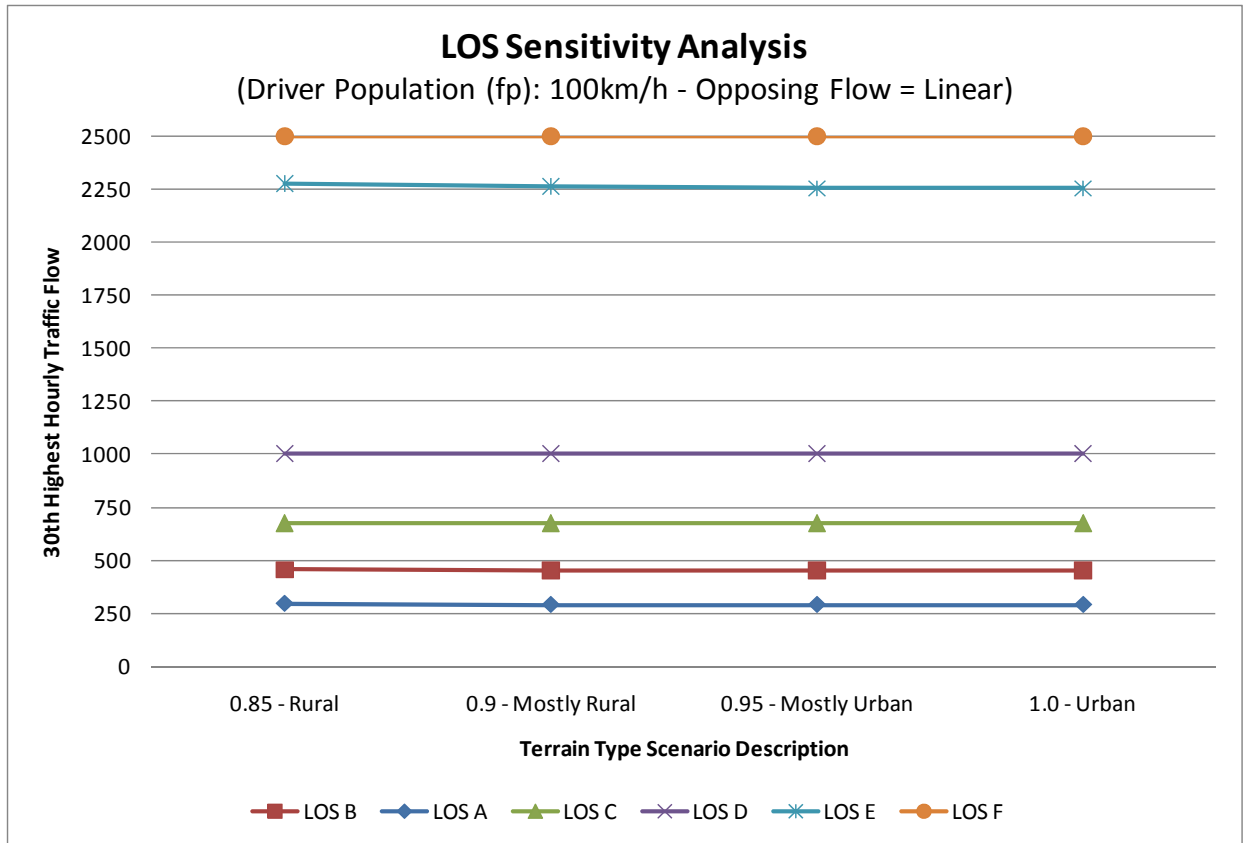
### 6.7 DRIVER POPULATION

The HCM methodology shows that LOS trigger volumes are *inelastic (insensitive)* in response to adjustments to Driver Population (fp) characteristics of the traffic stream on each network link (Refer to [Figure 12](#)). Driver population characteristics typically vary from 0.85 (representing seasonal, non-local driver composition, non-commuter traffic) to 1.0 (representing commuter traffic with local drivers in the traffic stream).

According to the sensitivity analysis, only LOS categories A, B and E significantly respond to changes in driver population characteristics. LOS category A and B respond to a change in driver population from 0.85 to 0.90. In both cases the LOS category trigger volume values reduce by 1.7% and 1.1% respectively. This finding was in contradiction with the expectation of the authors. It is generally expected that a traffic stream consisting of commuter traffic primarily comprising local (familiar) drivers would exhibit higher tolerances with respect to LOS categories than for traffic streams comprising non-commuter non-local drivers.

LOS C and D categories are non-responsive to changes in driver population. LOS category E responds minimally to driver population changes. For every 0.05 change in driver population, the LOS E trigger volume value reduces by 0.5%.

**Figure 12: Driver Population (fp) – LOS Sensitivity Analysis Results**



Scenario Statistics: 4 scenarios, 2000 links, Linear increasing traffic volumes, Interval: 0.05 Driver population change per scenario.

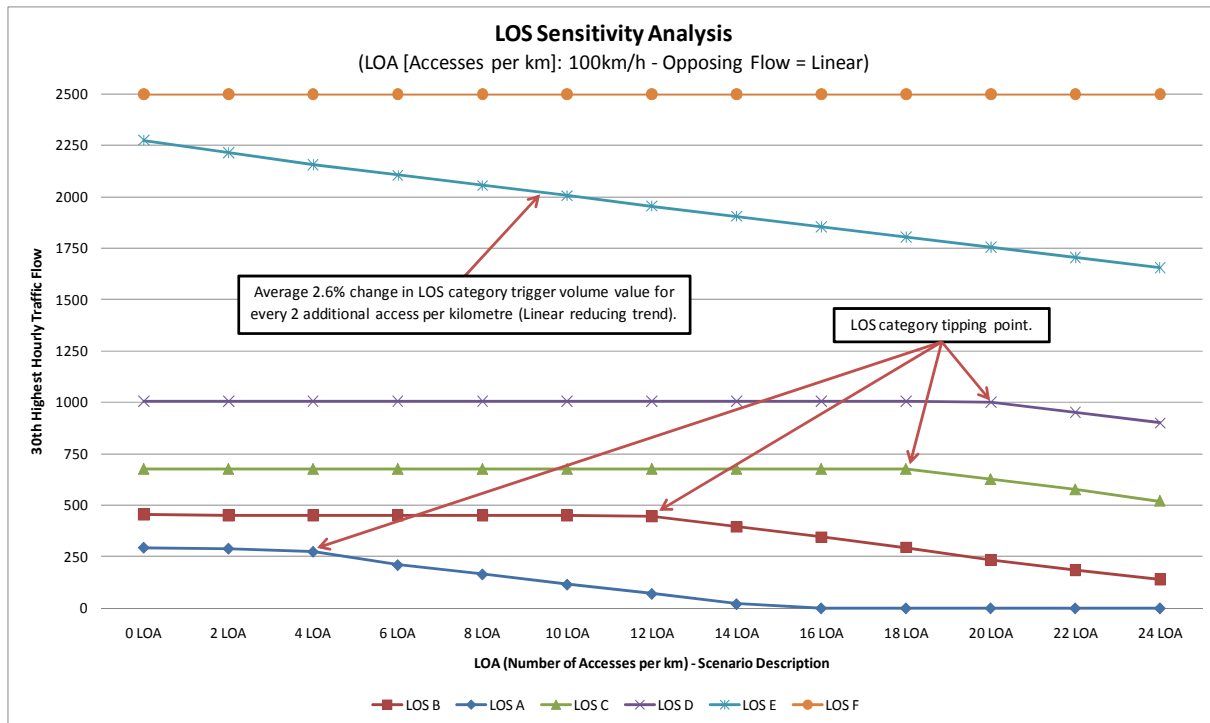
### 6.8 LEVEL OF ACCESS (ACCESSES PER KILOMETRE)

The HCM methodology shows that LOS trigger volumes are *highly elastic (highly sensitive)* in response to the number of access per kilometre of analysis network (Refer to [Figure 13](#)). The sensitivity analysis shows that all LOS categories respond to the number of accesses per kilometre on the analysis network. LOS categories A, B, C and D show minimal reductions in LOS category trigger volume values up to a specific tipping point whereby each LOS category shows drastic reductions in trigger volume values. LOS category A trigger volumes reduce drastically from 4 accesses/km terminating at 16 accesses/km. LOS category B trigger volumes reduce drastically from 12 accesses/km and LOS C and D exhibits the same trend from 18 and 20 accesses/km respectively.

LOS category E exhibits a linear decreasing trend with regards to reducing trigger volume values at an average reduction of 2.6% of trigger volumes for every 2 accesses/km added to the network. No particular tipping point was observed for LOS E within the range of accesses per kilometre analysed.

The sensitivity of answers to this parameters is significant and should therefore be determined and applied with care.

**Figure 13: Level of Access – LOS Sensitivity Analysis Results**



Scenario Statistics: 13 scenarios, 6500 links, Linear increasing traffic volumes, Interval: 2 accesses added per kilometre per scenario.

## 6.9 OPERATING SPEED

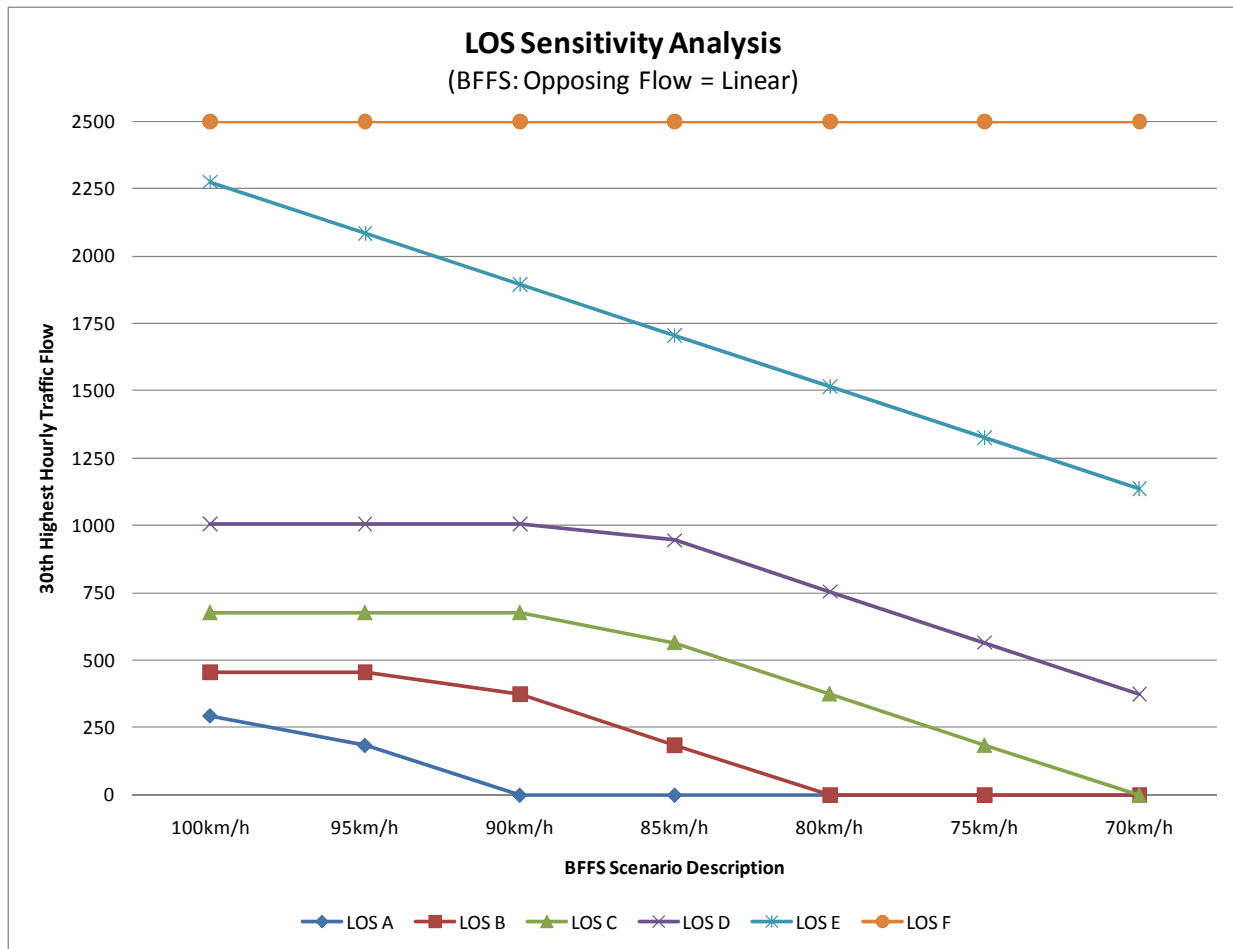
The HCM methodology shows that LOS trigger volumes are *highly elastic (highly sensitive)* in response to the operating speed of each link on the analysis network (Refer to [Figure 14](#)). The sensitivity analysis shows that all LOS categories respond to the link operating speed.

LOS category A responds immediately to a reduction in link operating speed from 100km/h to 90km/h. LOS category trigger volume values reduce at an average rate of 69% up to 90km/h at which point LOS A can no longer be attained by any link on the analysis network.

LOS categories B, C and D show no reduction in LOS category trigger volume values up to a specific tipping point whereby each LOS category shows drastic reductions in trigger volume values. These tipping points are 90km/h and 95km/h respectively. LOS B category trigger volume values reduce at an average rate of 56% from 95km/h up to 80km/h at which point LOS B can no longer be attained by any link on the analysis network. LOS C category trigger volume values reduce at an average rate of 50% from 90km/h up to 70km/h at which point LOS C can no longer be attained by any link on the analysis network. LOS D category trigger volume values reduce at an average rate of 21% from 90km/h and exhibit a linear decreasing trend from 85km/h operating speed and lower.

LOS category E exhibits an almost linear reducing trend with LOS category trigger volume values reducing at an average rate of 10% across all operating speed scenarios from 100km/h to 70km/h.

**Figure 14: Operating Speed – LOS Sensitivity Analysis Results**



Scenario Statistics: 7 scenarios, 3500 links, Linear increasing traffic volumes, Interval: 5km/h operating speed increase per scenario.

### 6.10 PERCENTAGE NO-PASSING ON EACH LINK

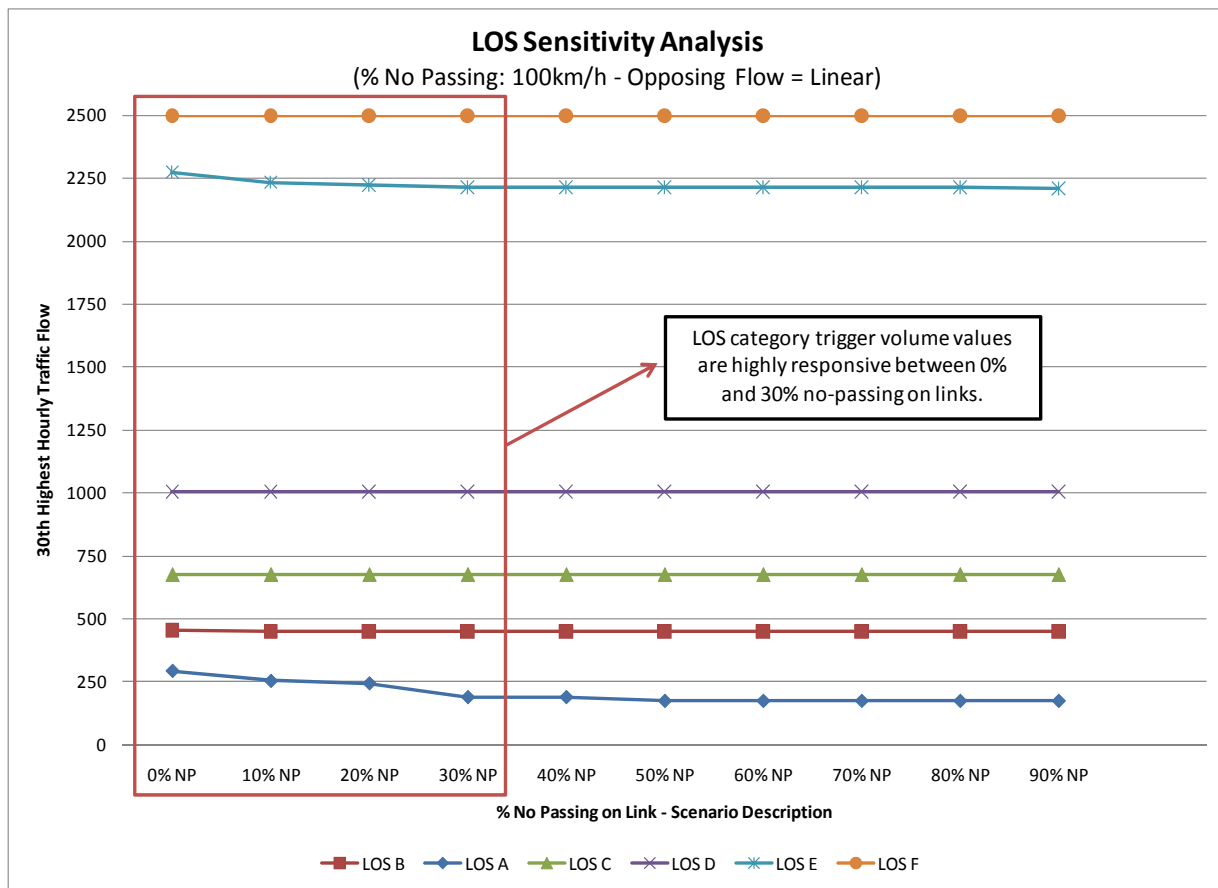
The HCM methodology shows that LOS trigger volumes are *relatively elastic (moderately sensitive)* in response to passing opportunities of each link on the analysis network (Refer to [Figure 15](#)). The sensitivity analysis shows that only LOS categories A, B and E respond to passing opportunity changes on the network. Furthermore, the analysis shows that LOS category trigger volume values become insensitive (inelastic) to changes in passing opportunities once the percentage no-passing on a link exceeds 50%.

LOS category A is most responsive of all LOS categories showing on average a 13% change in LOS category trigger volume values from 0% to 30% no-passing on the network. LOS category A shows the highest reductions in trigger volume values between 0% and 30% no-passing (average 13% trigger volume reduction) on network links and again at 50% (7.9% trigger volume reduction), where after it becomes completely inelastic.

LOS category B only responds at a 10% no-passing level with a 1% reduction in trigger volume values. LOS E, similar to LOS A, is most responsive from 0% to 30% no-

passing on the network showing on average a 1% change in LOS category trigger volume values.

**Figure 15: Percentage No-passing – LOS Sensitivity Analysis Results**



Scenario Statistics: 10 scenarios, 5000 links, Linear increasing traffic volumes, Interval: 10% no-passing (10% reduction in passing opportunities) on the network link increase per scenario.

## 7. CONCLUSIONS

Based on the methodology applied and analyses performed, the following conclusions can be drawn:

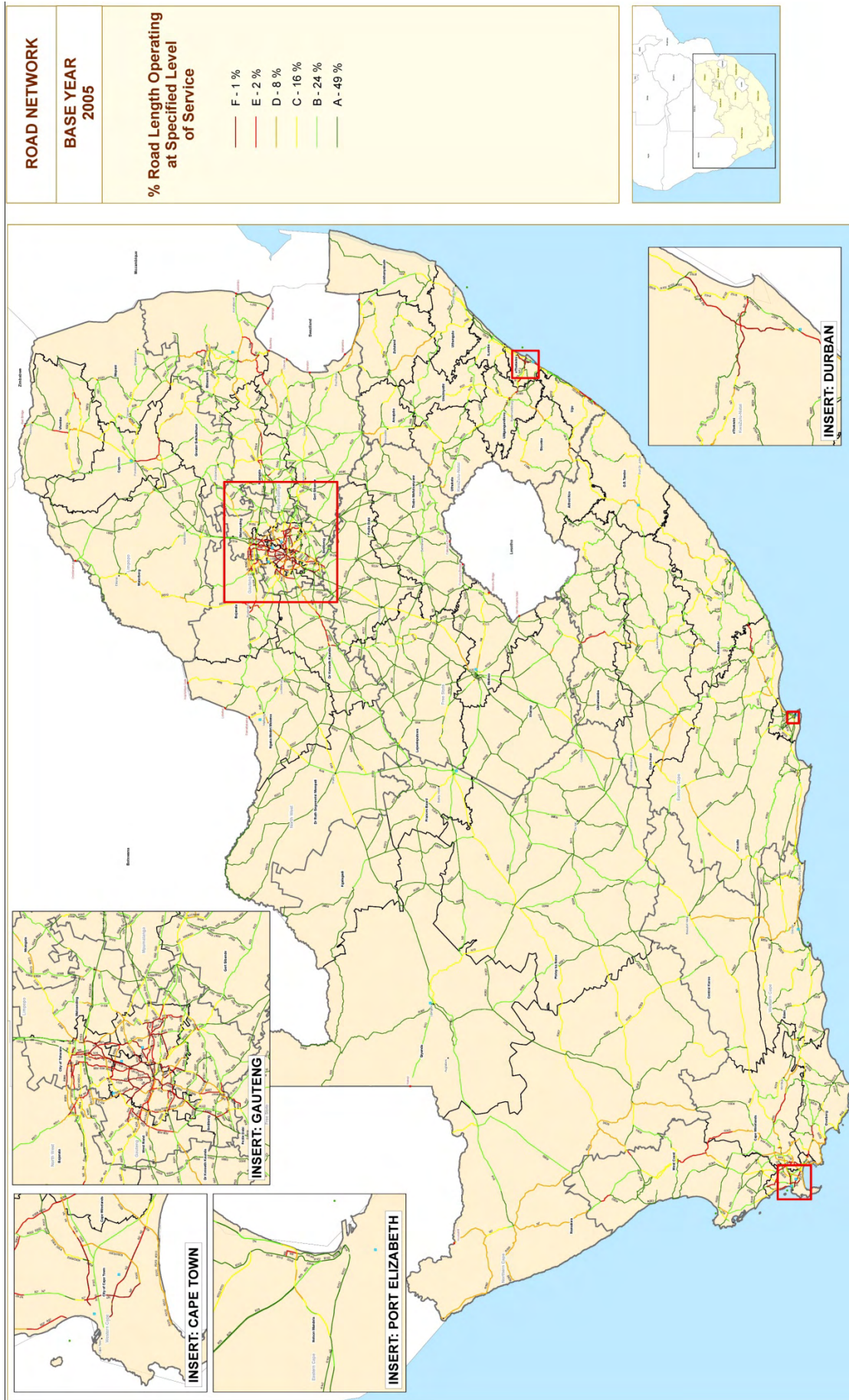
- The HCM 2000 two-lane and multi-lane freeway section analysis methodologies provide a sensible short term, quick yield, first order estimate of potential freeway road network capacity constraints.
- The current calculation sheets in the HCM documentation and software do not allow for calculation of large road networks with numerous links. The development of this computer model allows network-wide application of the HCM methodologies.
- Data collection in the form of reliable traffic counts and accurate road geometry and terrain information proved to be a challenge. The authors of this paper wish to make a call for dedicated data collection programmes with standardised methodologies and constant validation and verification in order to improve engineering analysis within the South African road transport environment into the future. The adage by Robert Kaplan still applies...“if you can’t measure it, you can’t manage it”.

- The HCM computer model proved particularly useful in performing sensitivity analyses on model parameters in order to determine where the data collection and model calibration focus should be aimed.
- The HCM computer model should be applied on a sketch-planning level and not for detail road section analysis for design input purposes. The HTM (developed by SANRAL) with the purposes detail road network link analysis and climbing lane requirement determination should be used for design level input.

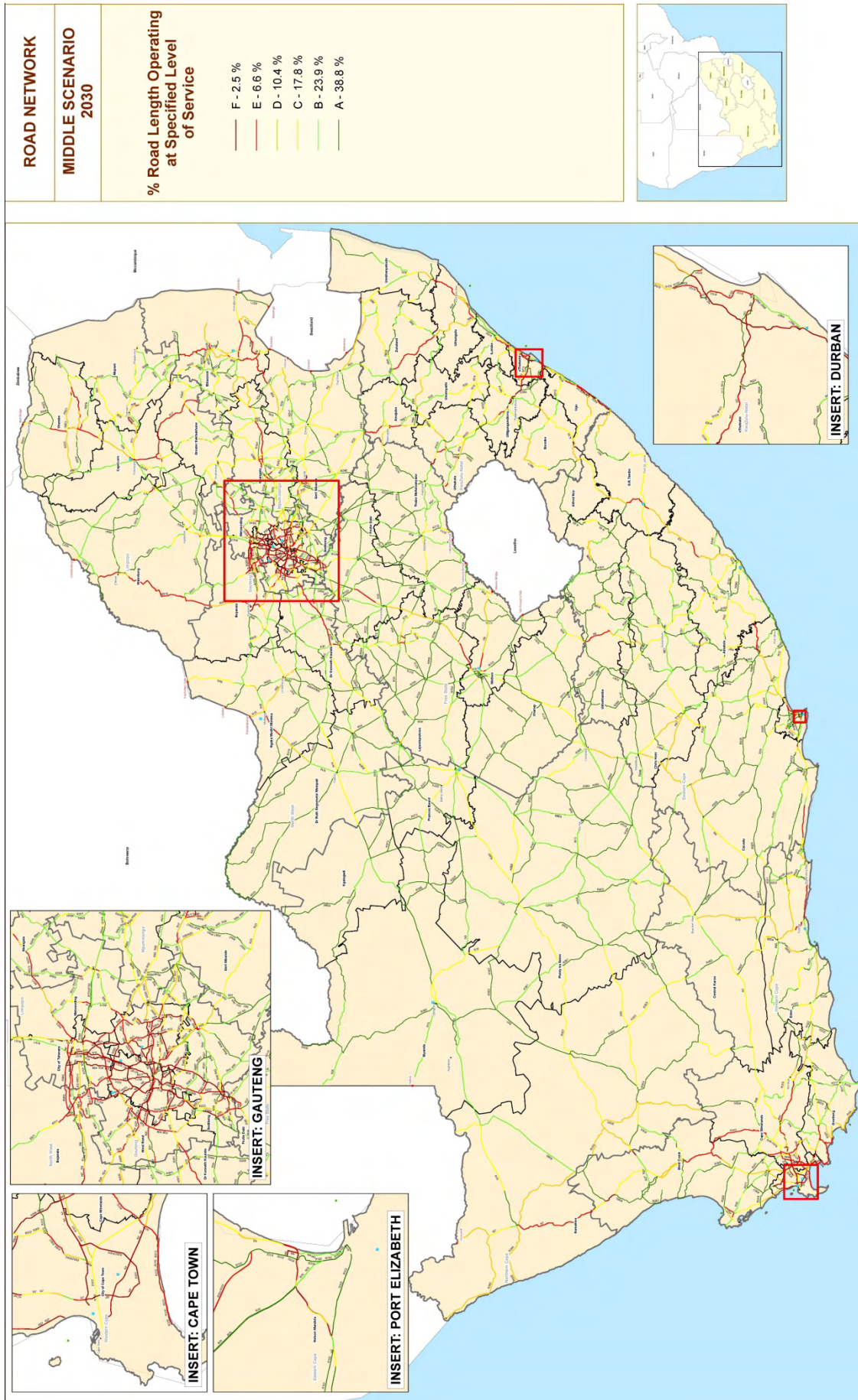
## **8. REFERENCES**

Transportation Research Board (2000). Highway Capacity Manual, Washington, D.C., 2000, ISBN 0-309-06681-6.

Appendix A: LOS Analysis Results for Base Year (2005)

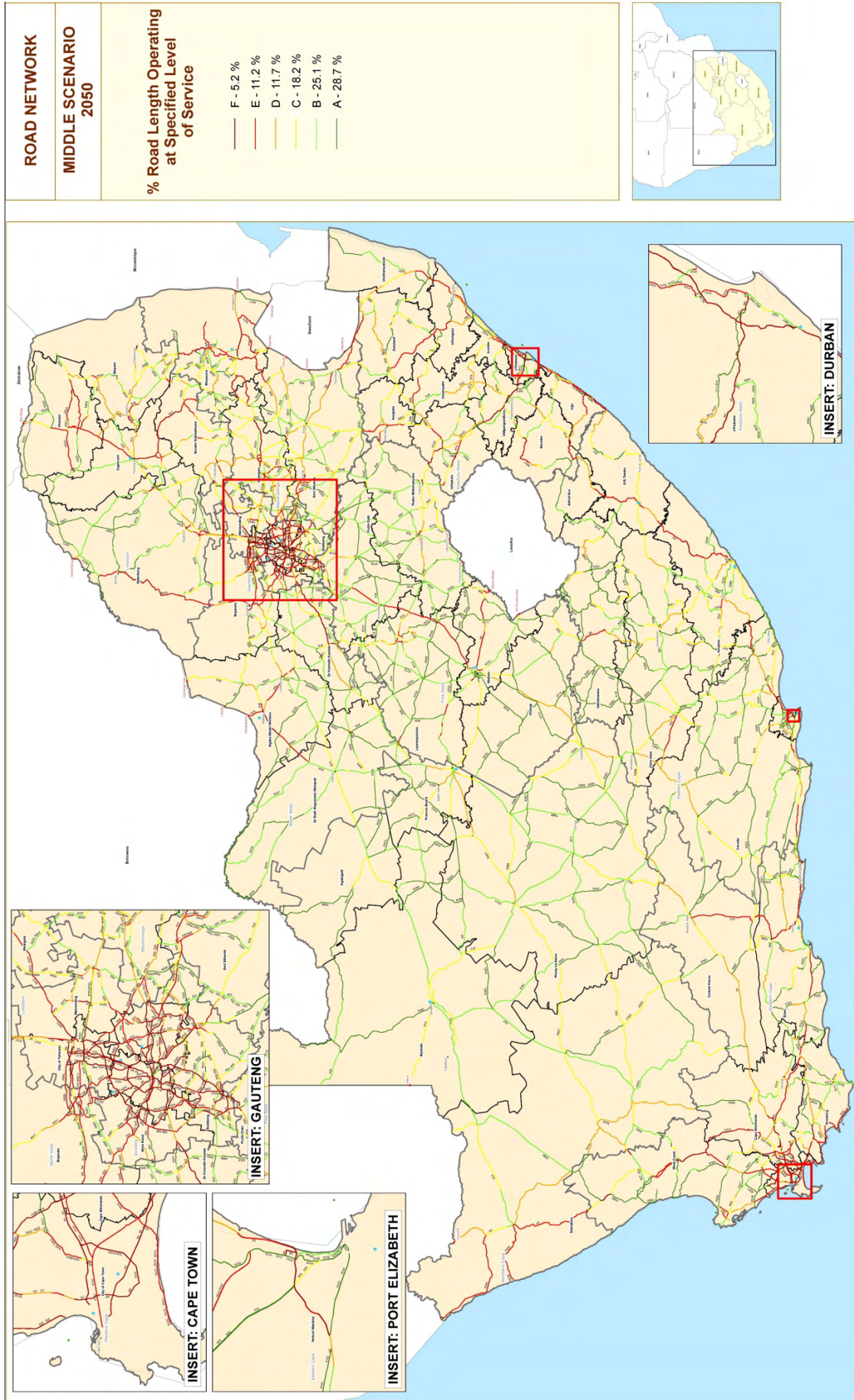


Appendix B: LOS Analysis Results for Analysis Year (2030)

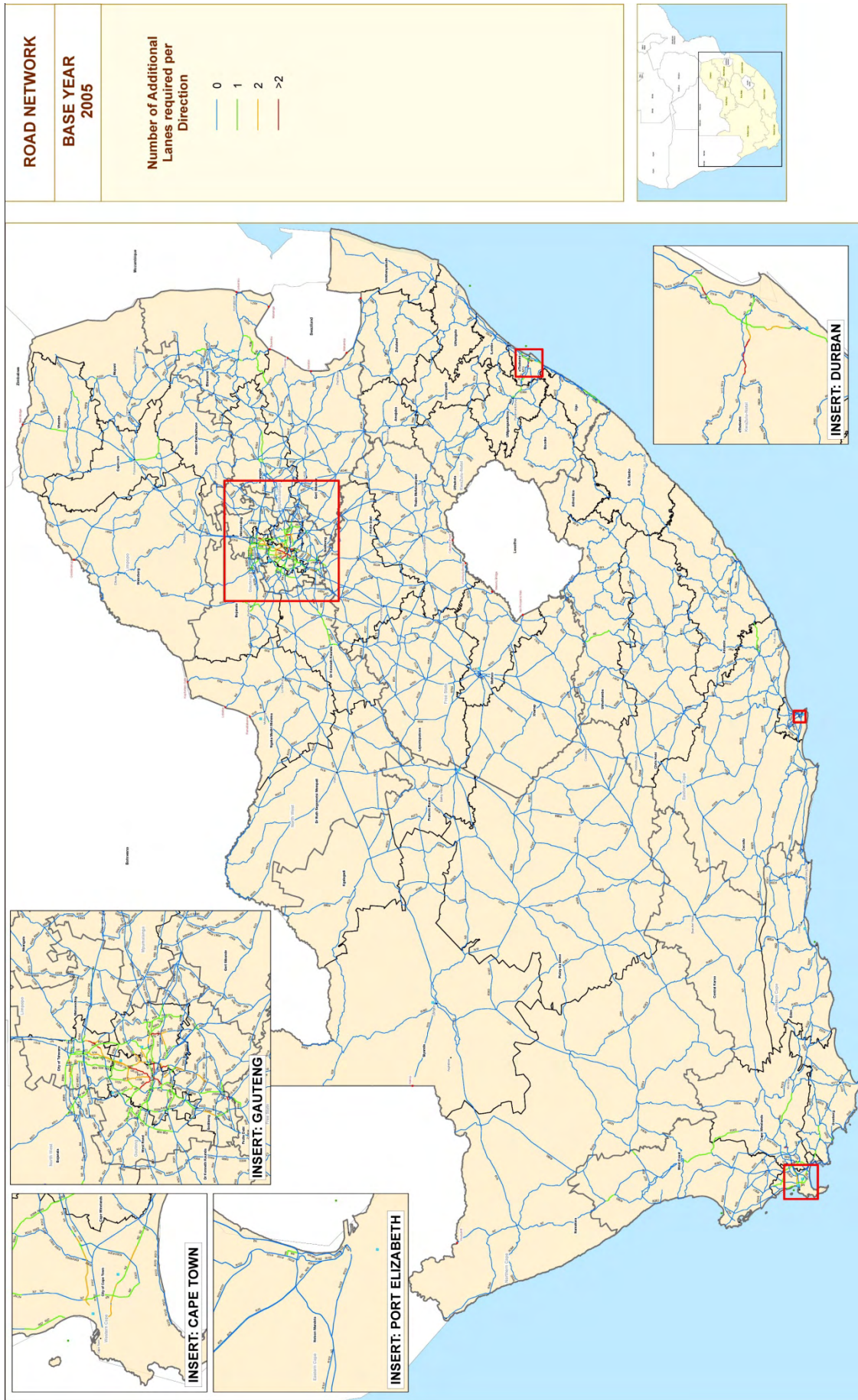




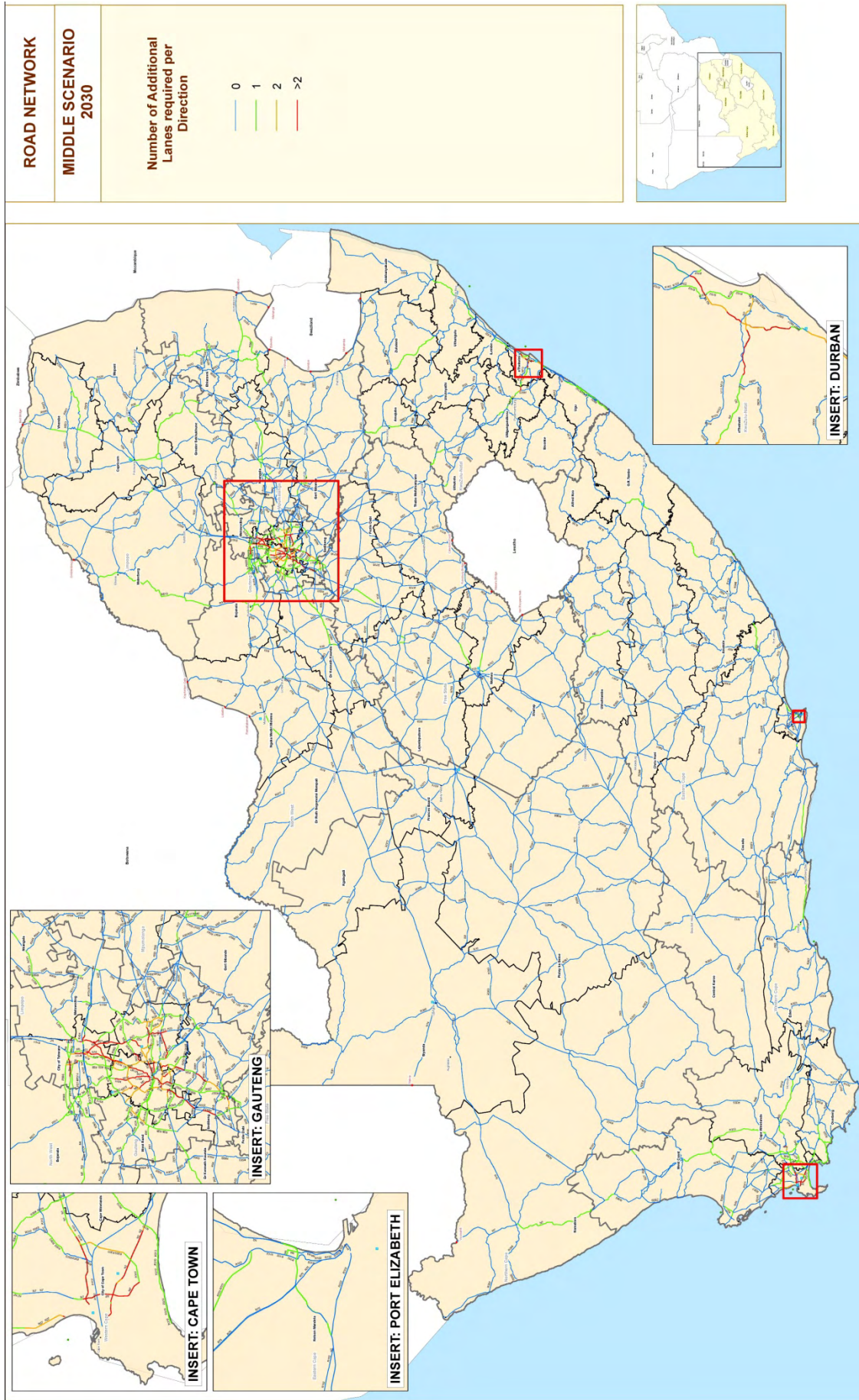
Appendix C: LOS Analysis Results for Analysis Year (2050)



Appendix D: Additional Lane Analysis Results for Base Year (2005)



Appendix E: Additional Lane Analysis Results for Analysis Year (2030)



Appendix F: Additional Lane Analysis Results for Analysis Year (2050)

